Bringing together UAS-based land surveying and procedural modelling of buildings to set up enhanced VR environments for cultural heritage

T. Adão
INESC TEC (formerly INESC Porto) and
University of Trás-os-Montes e Alto Douro
Vila Real, Portugal
telmoadao@gmail.com

L. Pádua, J. Hruška
Department of Engineering
University of Trás-os-Montes e Alto Douro
Vila Real, Portugal
{luispadua,jonash}@utad.pt

E. Peres, J. J. Sousa, R. Morais
INESC TEC (formerly INESC Porto) and
University of Trás-os-Montes e Alto Douro
Vila Real, Portugal
{eperes,jjsousa,rmorais}@utad.pt

L. G. Magalhães
ALGORITMI Center
University of Minho
Guimarães, Portugal
lmagalhaes@dsi.uminho.pt

***Abstract*—A methodology to rapidly produce environments that combine the intuition of *in situ* augmented reality (AR) with the commodity of virtual reality (VR) is proposed in this paper, by bringing together unmanned aerial systems (UAS) imagery and procedural modelling. While fully synthesized environments provide a very accurate visualization of the conserved parts of the real-world, missing parts - namely ruins - can be complemented with procedurally modelled structures. Regarding methodology's steps, firstly, a UAS flight mission gathers georeferenced imagery data about the site of interest. Then, the image set is converted to an accurate 3D model of the referred site, through photogrammetry. By considering the geographic information that also results from the previous process, ruins are manually outlined for georeferencing purposes. To complement ruins' missing information, virtual models of buildings are produced too, in a procedural modelling tool. Finally, at the full VR environment setup step, all elements are imported and subjected to geometric transformations that aim to match the procedurally modelled buildings with the outlined ruins. To improve the insight about the process work-flow, system's architecture and implementation are presented along with a case-study regarding a historically relevant site - Vila Velha's city gates (Vila Real, Portugal) - and preliminary results.**

***Keywords*—UAS, UAV, Photogrammetry, Procedural Modelling, GIS, Cultural Heritage, Virtual Reality**

I. Introduction

Motivating public participation on cultural heritage constitutes an important factor to spread the knowledge related with ancient folk groups and their way of living that, in turn, lead to the explanatory evidences defining modern society cultural identity. Moreover, such promotion has the potential of making room for emerging business models based on culture and history, empowering the sustainability of museums and other similar areas, as well as researching tasks related with cultural heritage.

978-1-5386-2080-9/17/$31.00 © 2017 IEEE

Virtual reality (VR) and augmented reality (AR) have demonstrated their ability to establish bridges between the public and cultural heritage by offering compelling and entertaining solutions for visiting historically relevant sites that are - in not rare cases - in an advanced state of degradation. In spite of those two kind of approaches' suitableness for cultural heritage reconstitution, they differ in presence and mobility requirements. In AR, more specifically in the case of *in situ* experiences, participants are allowed to move freely in a real environment that can, expectedly, improve their intuition about past monuments through the visualization of virtual content augmented in the actual place, at real-time. Of course, *ex vivo* experiences might be carry out using, for instance, improvised markers for tracking; although, such approach is likely to have impact on intuition inasmuch as users lost contact with the real-world environment context. On the other hand, VR allows the participants to see fully synthesized environments delivered by proper equipment (e.g. regular screening devices, head-mounted displays) in their own accommodation.

For virtual visitations in the context of tourism and/or training, indoor experiences powered by museums or even education, VR presents itself as a better alternative, due to its presence/intuition trade-off and mobility requirements. Although, virtual contents - namely, 3D models - are usually very laborious and time consuming to produce, specially when a high level of resemblance with the parts that are still conserved in the real-world is needed.

Thereby, in this paper, a methodology to rapidly produce environments combining the intuition of *in situ* AR with the commodity of VR is proposed along with a system, by bringing together unmanned aerial systems (UAS) imagery and procedural modelling. While fully synthesized environments provide a very accurate and fairly natural visualization of the conserved parts of the real-world, missing parts (e.g. ruins) can be complemented with procedurally modelled structures. Regarding the methodology's steps, firstly, a UAS flight mission gathers data about the site of interest. Then, using a photogrammetric process, data is converted to an accurate 3D model of the referred place. By considering the geographic information that also results from the previous process, ruins are manually outlined for georeferencing purposes. To complement ruins' missing information, virtual building models are produced too, using a procedural modelling approach [1]. A final process is responsible for setting up the full VR environment by importing everything and carrying out (automatic) alignment, dimensioning and rotation operations to match the procedurally modelled buildings with the identified ruins, accordingly to a set of association rules manually specified or randomly determined.

The remaining of this paper is organized in 5 sections, besides introduction: in the next one, a literature review on digital cultural heritage solutions involving VR/AR, UAS, photogrammetry and procedural modelling is provided; then, the methodology for producing VR environments that combine UAS-based imagery with procedural modelling is presented right before system's implementation section; finally a case-study is shown followed by conclusions and future work.

II. Digital cultural heritage related work

Several VR and AR solutions ranging within the virtual continuum of Milgram and Kishino [2] have been proposed for cultural heritage, archaeology, history and related areas. Regarding the former, several works for museums have been reported, including immersive setups to visualize lost cultural heritage with, haptic interfaces to manipulate virtual sculptures [3] and systems to interact with 3D models built up from 3D scanning techniques [4]. Virtual museums [5], VR platforms [6] and dynamic web-based frameworks [7] concerned with the public participation in cultural heritage field as well as knowledge dissemination have been proposed as well. In [8], those concerns are addressed by providing interfaces for realistic visualization of digitally preserved sites with restrictive access. Others, developed design tools focusing the production of hypothetical virtual models [9] and for teaching applications [10]. Also in the teaching/learning of cultural heritage, serious games (SG) - mostly developed for VR - have shown benefits in complementing traditional practices of knowledge propagation (museums, books, etc.) [11]. Regarding AR, one of the first impacting solutions for archaeology was ARCHEOGUIDE [12, 13] which allowed visualization of virtual reconstructions upon real ruins. Later, in [14], a similar approach was followed. A "magic glass" [15] giving information about places' past was proposed in the meanwhile. Ikeuchi [16] developed a visitation tram that navigates inside a CAD model while some important historical events are displayed. Blanco-Fernández et al. [17] explored the AR pedagogical potential with a role-playing system focusing historical battles. In previous work [18], MixAR system was developed to provide visualization of virtual models seamlessly aligned upon real ruins, in context of *in situ* visitation.

Clearly, AR solutions for cultural heritage purposes, more specifically, in the context of visitation, demands users to be in the actual place to learn from the experience. Otherwise, representative scenarios using visible markers can do the job but with a likely lack of intuitiveness. On the other hand, to provide a realistic and convincing VR environment conserving the *in situ* experiences intuition, burdensome modelling tasks must be carried out to produce faithful virtual scenarios. One of the possible ways to address those issues is to integrate UAS imagery and photogrammetry processes capable of producing realistic virtual environments that are actually congruous with the real place.

Land surveying can be a quite challenging task [19] to be performed with the traditional methods like terrestrial-based topography, photogrammetry or laser scanning. Alternatively, UAS have been increasingly used to the same end [20] as a cost-effective and non-invasive approach. Several authors exploited fixed-wing or multi-rotor UAVs capabilities to survey historically relevant elements like churches [19], temples [21], ancient ruined cities [22], ancient mining places [23], post-disaster assessment [24, 25], landscape heritage analysis [26], among others. Photogrammetry - the process behind most of the previously addressed surveying works - can be defined as a range of techniques by which 3D properties of an object are derived from 2D images [27]. According to [28], photogrammetric process pipeline consists of the following steps: camera calibration and orientation, image point measurements, 3D point cloud generation, surface generation and texture mapping. Notwithstanding UAS surveying and ptotogrammetric processes importance for cultural heritage, there is one noteworthy gap that must be address: the recovery of severely damaged or lost structures. Towards that specific issue, procedural modelling has been widely applied to allow experts proposing hypothetical virtual reconstructions, semi- or fully automatically.

Focusing procedural modelling of exterior facades, Dikaiakou et al. [29] proposed a method based on photographs, building's outlines from geographic information system (GIS) and templates for digital preservation. Others, addressed virtual reconstructions of historical monuments (e.g. Puuc-style buildings [30] and Neo-Gothic chapels [31]) and places (e.g. ancient Rome [32]) through computer generated architecture (CGA) [33]. With a different approach Liu et al. [34] proposed a smart architect system relying on ontologies and user inputs to recover China's cultural heritage. Edelsbrunner et al. [35] presented a cylindrical coordinate system to procedurally develop round elements such as towers, barrel vaults and crossed-vaults valuable for historical buildings reconstruction. Regarding the procedural generation/reconstruction of virtual buildings with interiors, Rodrigues et al. [36, 37, 38, 39, 40, 41] developed a set of noteworthy works involving Vitruvius rules [42], L-systems, multilayer graphs, among others, to address ancient roman houses. Recently, Adão et al. [1, 43, 44] im-

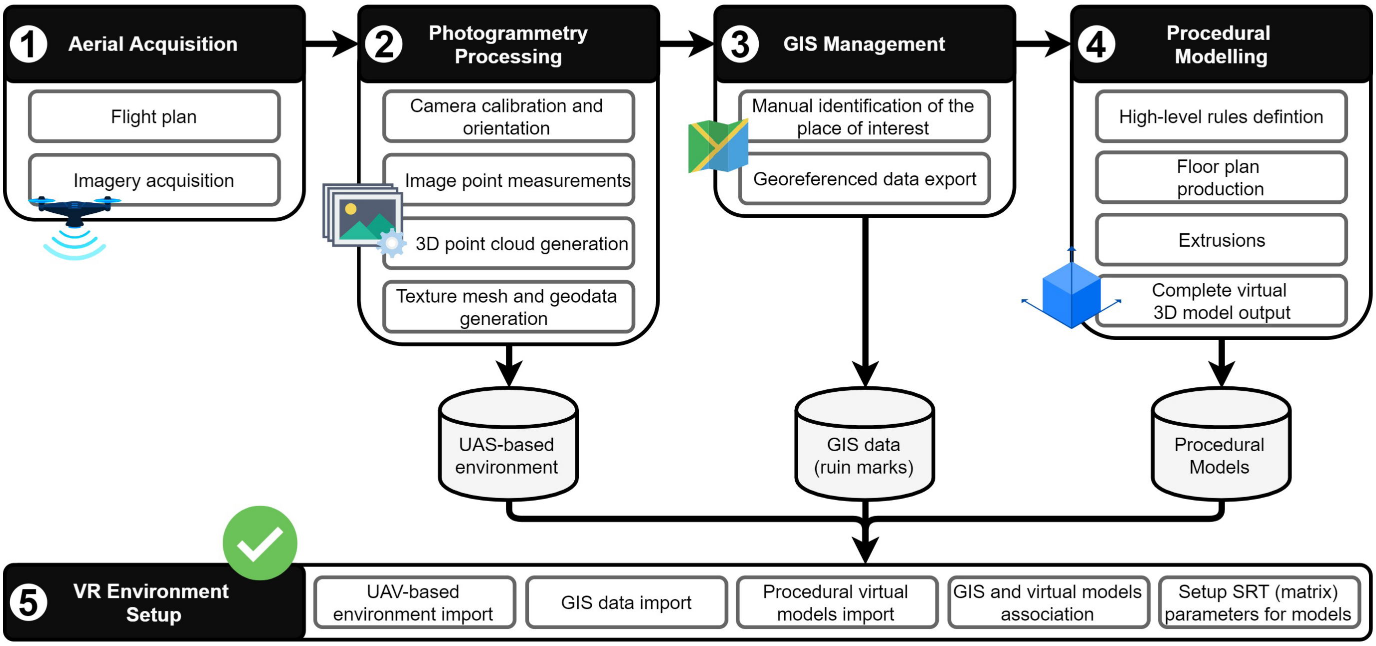

Fig. 1. Proposed methodology, composed of five processes: aerial acquisition referring to UAS-based surveying of the place of interest, photogrammery processing that is responsible for producing the virtual model of the surveyed area in four general steps identified by [28], GIS management wherein users outline ruins, procedural modelling in which virtual buildings [1] are produced to be, later on, superimposed to ruins and, finally, VR environment setup importing all of the previously produced elements to mount the full VR environment by automatically carrying out geometric transformations - scaling (S), rotation (R) and translation (T) - to properly place the procedural virtual buildings upon the ruin marks.

plemented an ontology-based procedural modelling approach capable of producing coarse virtual building models with floor-plans outlined by arbitrary shapes and divisions formed by convex polygons. This work was used to produced the virtual buildings used in the methodology presented in this paper.

Next section is devoted to the presentation of a methodology for setting up enhanced VR environments which, essentially, integrate: (1) digital representations of cultural heritage sites including ruins, based on UAS land surveys; and (2) hypothetical virtual buildings, procedurally modelled to complement ruins' missing information. Thus, *ex vivo* VR shall benefit from an intuition level similar to the one that characterizes *in situ* AR and from the data enrichment provided by procedural modelling.

III. Methodology Proposal

The proposed methodology for cultural heritage recovery (Fig. 1) intends to gather the intuitiveness of *in situ* AR and the commodity of VR systems by bringing together two main approaches: photogrammetry processing under the imagery collected by an UAS to produce faithful environments based on the real place of interest and procedural modelling to complete the missing or severely damaged structures - i.e., ancient buildings that turned into ruins - with hypothetical virtual reconstructions. More specifically, there are five main processes involved: aerial (data) acquisition, photogrammetry processing, GIS management, procedural modelling, and VR environment setup. Next subsections will address each one of the referred processes in more detail.

A. Aerial acquisition

Aerial acquisition process consists in surveying a place of interest (ideally, a cultural heritage area) with a UAS - composed by a UAV and a RGB camera - capable of autonomously executing flight missions with the aim of collecting imagery data. To that end, the presence of the following features are crucial and, thus, assumed for the rest of this explanation:

- planning mission software, usually provided by manufacturer;
- inertial and positional sensors for orientation and location control purposes;
- autopilot module for autonomous flights.

Firstly, a flight plan must be set up in a proper software system compatible with the UAV in use, wherein an aerial space is specified (an interactive GIS tool is usually provided to that purpose). Then, a trajectory type is defined (e.g. simple or double grid) as well as frequency for image capturing. A trade-off between information completeness and computational resources must be found by the operator who should take into account that more pictures means greater accuracy for subsequent photogrammetric process but, also, higher computational burden. After takeoff, UAV is oriented to the starting point of the flight mission and guided all over the way by its autopilot module. During the predefined path, pictures are stored in the device's storage system for further accessing and handling, as it is addressed in the next subsection.

B. Photogrammetry processing

Photogrammetry allows to obtain reliable 3D models through pictures that result from the UAS flight. The process behind the goal involves the following general steps, according to [28]: camera calibration and orientation, image point measurements, 3D point cloud generation, surface generation and texture mapping. After camera calibration - which is of major importance for obtaining accurate models -, image measurement can be performed by means of automatic or semi-automatic procedures. The first case, which allows obtaining a dense point clouds even in situations of inaccuracy and missing parts, is the most relevant for this methodology proposal since it does not require the intervention of an operator. Thus, the textured mesh representing the real-world environment (site of interest) can be autonomously processed by a machine that, in the end, outputs, not only the mesh, but also geodata profiling site location.

C. GIS management

Georeferenced data produced by the previous process can be displayed in a GIS software wherein the user is able to identify ruins by simply drawing contour polygons upon them. Such elements must be then exported to be handled by the VR environment setup process which is responsible for associating the georeferenced ruins with the procedural modelling models generated by another process that will be explained in the next subsection.

D. Procedural modelling

Procedural modelling process relies in a tool [1] that is used to deterministically derive virtual traversable building models as hypothetical reconstructions for missing structures. Regarding the core of the generation process, an adapted treemap approach subdivides the building layout into floor-plan areas, ranging from rectangles to arbitrary shapes. Moreover, a method concerning internal room walls adaptation is supported. Then, a set of operations is performed, from the marking transitions step to the walls' extrusion process that provides the 3D aspect. A CityGML-based [45] building ontology, planned to be extensible to specific architecture styles, regulates the whole generation process through sets of ontology-based grammar rules obtained either deterministic or stochastically.

Through the use of the referred procedural modelling tool, user is responsible for providing rules to ensure a coherent building generation (regarding rooms connectivity, relation between dimensions and height, etc.). Geometric transformation (rotations, translations and scaling) do not have to be a concern inasmuch as the VR environment setup process will handle all of them automatically, as it will be promptly pointed out thereafter.

E. VR environment setup

All the elements previously produced converge in a process named VR environment setup. Firstly, the UAV component is loaded into the VR environment and then GIS elements (ruin marks) and 3D virtual models are imported and associated. If the configuration file that establishes rules for model-GIS association is present, then models are assigned to GIS in accordance. Otherwise, an assignment based on pseudo-random generation is carried out. The next step is responsible by properly rotating, translating and scaling the virtual models, based on the orientation, position and shorter edge of the minimal bounding box of the respective GIS marks. The work-flow related with these operations is depicted in Fig. 2. Of course, there is an implicit process that converts geographic coordinates to relative metric distances [46].

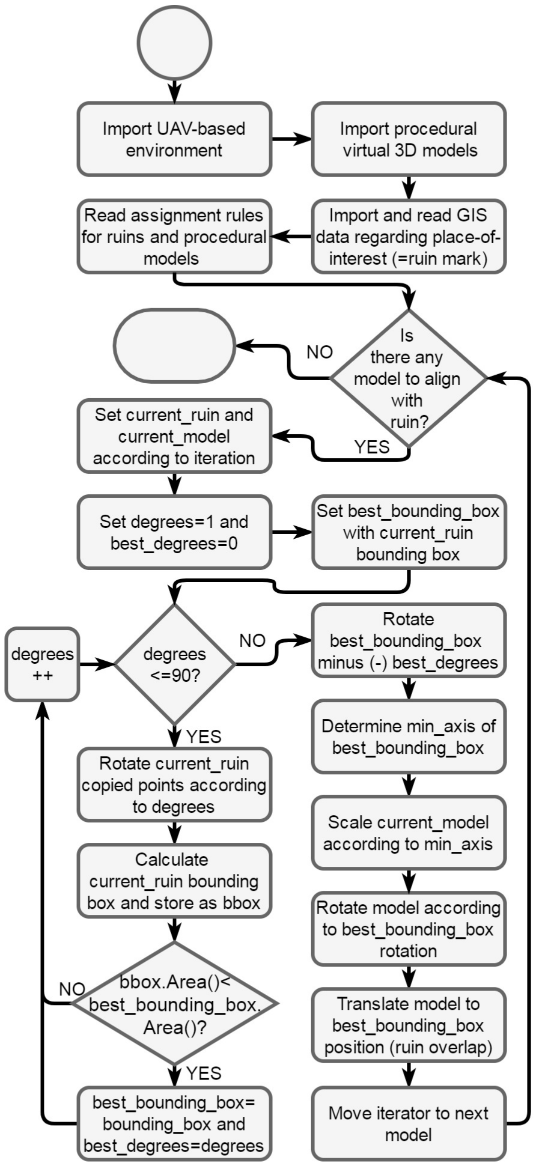

Fig. 2. Detailed work-flow of the VR environment setup. Firstly, UAS-based virtual environment, GIS data regarding ruin marks and procedural models are imported. Afterwards, a sequence of operations is performed to properly place each (procedural) virtual model upon its assigned ruin. Essentially, the minimal bounding box of each ruin is determined and, then, the respective virtual model is scaled, rotated and translated accordingly to it.

The following section will present this methodology implementation, as well as the concrete technologies that allow to achieve the goals that are being proposed in this paper.

IV. System implementation

To support the proposed methodology, a complying architecture (Fig. 3) was designed having in mind a system implementation. Making part of that architecture, there are four modules that, directly or indirectly, produce data for a fifth one. This last module is responsible for setting up the VR environment including virtual models procedurally produced and strategically aligned upon the ruins representations which belong to a wider virtual model representing the cultural heritage area of interest. More specifically, there is an aerial acquisition module (AAM) that, essentially, consists in a DJI (Shenzhen, China) Phantom 4 UAV for gathering imagery data from the area of interest. Imagery is, then, submitted to a photogrametry processing module (PPM) integrating Pix4D (Lausanne, Switzerland) software to perform operations that lead to the production of the virtual model representing the scanned area. Considering geographic data that also results from the previous process, ruins must be georeferenced to identify the spots requiring procedural modelling completion. To this end, a GIS module (GIM) powered by Google Earth (Google, California, United States) software which provides intuitive and easy-to-use geographic demarcation and data export functionalities was included. The production of the virtual models intended to overlap demarcated ruins lying on the virtual environment representing the area of interest is carried out by a procedural modelling module (PMM) that outputs hypothetical building representations based on a set of user defined rules. Finally, VR environment setup module (VRESM) imports the virtual representation of the scanned area along with the GIS data to know how to properly place, scale and align the procedurally modelled virtual buildings upon the georefenced ruins, thereby achieving the final VR environment wherein those various elements are mixed. A C# algorithm implemented for Unity 3D (Unity Technologies, California, United States) manages last module's operations, in accordance with the work-flow addressed in the previous section.

The next couple of subsections will address: (1) data preparation activities - specifically, aerial land surveying, cultural heritage area virtual model's photogrammetric production, GIS-based ruins demarcation and procedural modelling of hypothetical virtual buildings to be placed upon ruins - as well as (2) the implementation of the VRESM that automatically builds the enhanced virtual scenario, by integrating data resulting from the remaining modules.

A. Activities towards data preparation

AAM's Phantom 4 is used for capturing aerial pictures, after flight planning and configuration. Next, images are downloaded from UAV storage unit and processed by Pix4D software integrated in the PPM, which aligns images according to associated coordinates, finds tie points in them and generates a point cloud and mesh to output a faithful georeferenced triangulated virtual model of the surveyed place of interest, whose quality might be affected by aspects such as altitude of the flight, UAV camera specifications, time of day, weather conditions and Pix4D settings (Fig. 4).

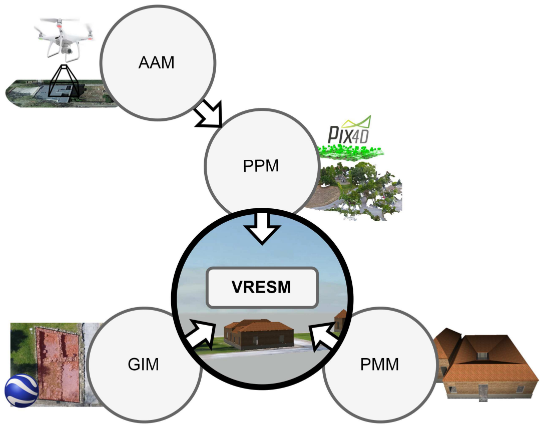

Fig. 3. Methodology's supporting architecture towards system implementation, composed of five modules: (1) AAM consisting in a Phantom 4 UAV for land surveying purposes; (2) PPM for automatically setting up the 3D model of the surveyed area, through Pix4D software; (3) GIM powered by Google Earth to enable area's ruins demarcation; (4) PMM for the production of hypothetical virtual buildings that aim (virtual) ruins superimposition; and (5) VRESM which, essentially, relies in an algorithm - developed for Unity 3D - that considers data resulting from the other modules to properly align the procedurally produced virtual models with the ruins belonging to the virtual model of the scanned area of interest.

Fig. 4. Example of a Pix4D output as a result of photogrammetric processing upon imagery set regarding city gate's old ruin, situated in Vila Real (Portugal). Imagery was collected using a Phantom 4 flying at 40m of altitude, in double grid mode, with an overlap of 90% and 80^{o} of camera orientation. 107 photos were taken in 4min and 10s. Some shadows burned in the 3D model reflect the influence of the light conditions (sunny day) over pictures acquisition task.

Then, using Google Earth (selected software for GIM), ruins are delimited with polygons which, in turn, are exported as Keyhole Markup Language (KML) files. This is followed by the procedural modelling of virtual buildings that complement the surveyed environment by filling the ruins with hypothetical representations. To that end, a deterministic tool available in the PMM is used to interactively produce virtual buildings by drawing and parametrizing floor-plans (Fig. 5). Since the VRESM automatically carries out scaling, translation and rotation operations to make the generated buildings closely match the ruin marks provided by GIM, dimensions do not have to be a concern of the user who shall only ensure virtual models' coherence by avoiding, for example, disparities between buildings' area extension and height or divisions mistakenly connected.

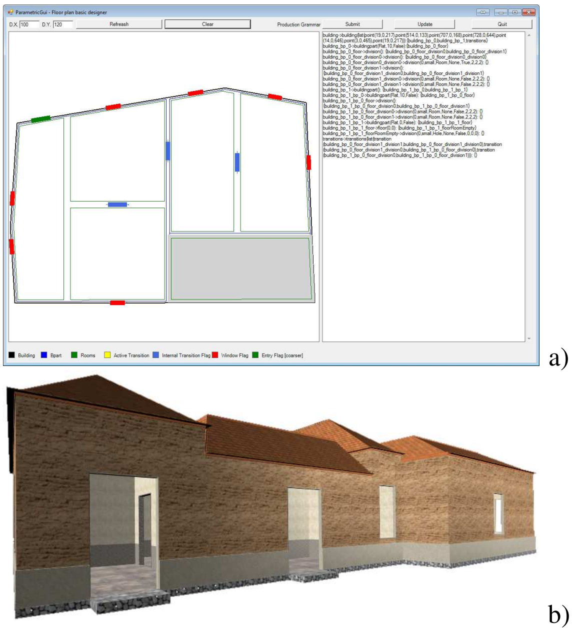

Fig. 5. Procedural modelling tool included in the PMM: a) presents the deterministic parametric tool - proposed in [1] - with a floor-plan drawing pane, an area for grammatical rules automatically extracted during user drawings and parametrizations and, also, color captions to aid in the identification of drawn elements; b) depicts a virtual building model produced by the PPM's deterministic (parametric) tool.

Optionally, an eXtensible Markup Language (XML) file can be created to relate the previously produced virtual models with the delimited ruins. If the XML configuration is skipped, a random assignment is assumed, as it is explained in the next subsection.

B. VRESM implementation

The process responsible for bringing together the previously referred elements was implemented in Unity 3D to constitute the VRESM. The first steps carried out by it regards to the importing of UAS-based virtual model depicting the cultural heritage place, GIS data and procedurally modelled buildings. Virtual models and GIS elements are subsequently associated in a step which supports both presence or absence of user defined rules. More specifically, if there is an XML file specifying what models should be associated to which ruins, then such rules are followed, as long as they respect the following format:

```
<collection>
        <tupple>
                <gis>GIS_A</gis>
                <model>MODEL_A</model>
        </tupple>
        <tupple>
                <gis>GIS_B</gis>
                <model>MODEL_B</model>
        </tupple>
        ...
</collection>
```

Otherwise, an assignment based on pseudo-random is carried out. For each ruin to be superimposed by a building, a minimal bounding box is determined including its centroid position, orientation and shorter edge length. For each virtual building to be placed in the VR environment, rotation, translation and scaling operations are carried out to transform it accordingly with the features of the minimal bounding box determined for the associated ruin mark.

Next section will address a case study for elucidation and preliminary evaluation purposes.

V. Vila Velha's case study and preliminary results

To evaluate methodology/system regarding its effectiveness in mounting VR environments composed of both UAV-based virtual environment and procedurally modelled buildings, a preliminary test was carried out, considering the vicinities of the Vila Velha's Museum (Vila Real, Portugal) which is an emblematic place wherein the city gates' ruins lie on. The sequence of steps previously addressed was faithfully applied: AAM's Phantom 4 was used to capture the imagery upon Museum's vicinities; then, using PPM's Pix4D, a 3D model of the place was produced along with KML files that profile it in terms of location; afterwards, the KML files were imported to GIM using Google Earth wherein three ruins were delimited, one of them identifying city gates' leftovers and two others representing fictitious ruins for testing purposes; finally, three hypothetical virtual models were produced by PMM - integrating a procedural modelling software developed in [1] - to be placed upon the ruins. Those elements - which are split by folders regarding UAS-based environment, GIS elements and procedural models - were automatically imported and processed by the VRESM's Unity 3D implementation, producing the results depicted in Fig. 6.

VI. Conclusions and future work

A methodology and system capable of rapidly producing enhanced environments that join the intuition of *in situ* AR with the commodity of VR were proposed in this paper. The main goal is to take the cultural heritage places to the users by presenting faithful virtual environments depicting the real-world places of interest while complementing damaged or missing structures with hypothetical virtual buildings procedurally modelled. Virtual tourism, education and business models related with museology can be the main areas benefiting from the proposed methodology/system.

Summing up, the following steps constitute the proposed solution: firstly, the real-world place of interest (cultural heritage site) needs to be scanned by a UAS that gathers the images that are then submitted to a photogrammetric process to produce the respective virtual environment. Afterwards, ruins need to be manually outlined in a GIS software while the procedural modelling tool is used to develop the virtual buildings that will superimposed each one of the geographic marks. Lastly,

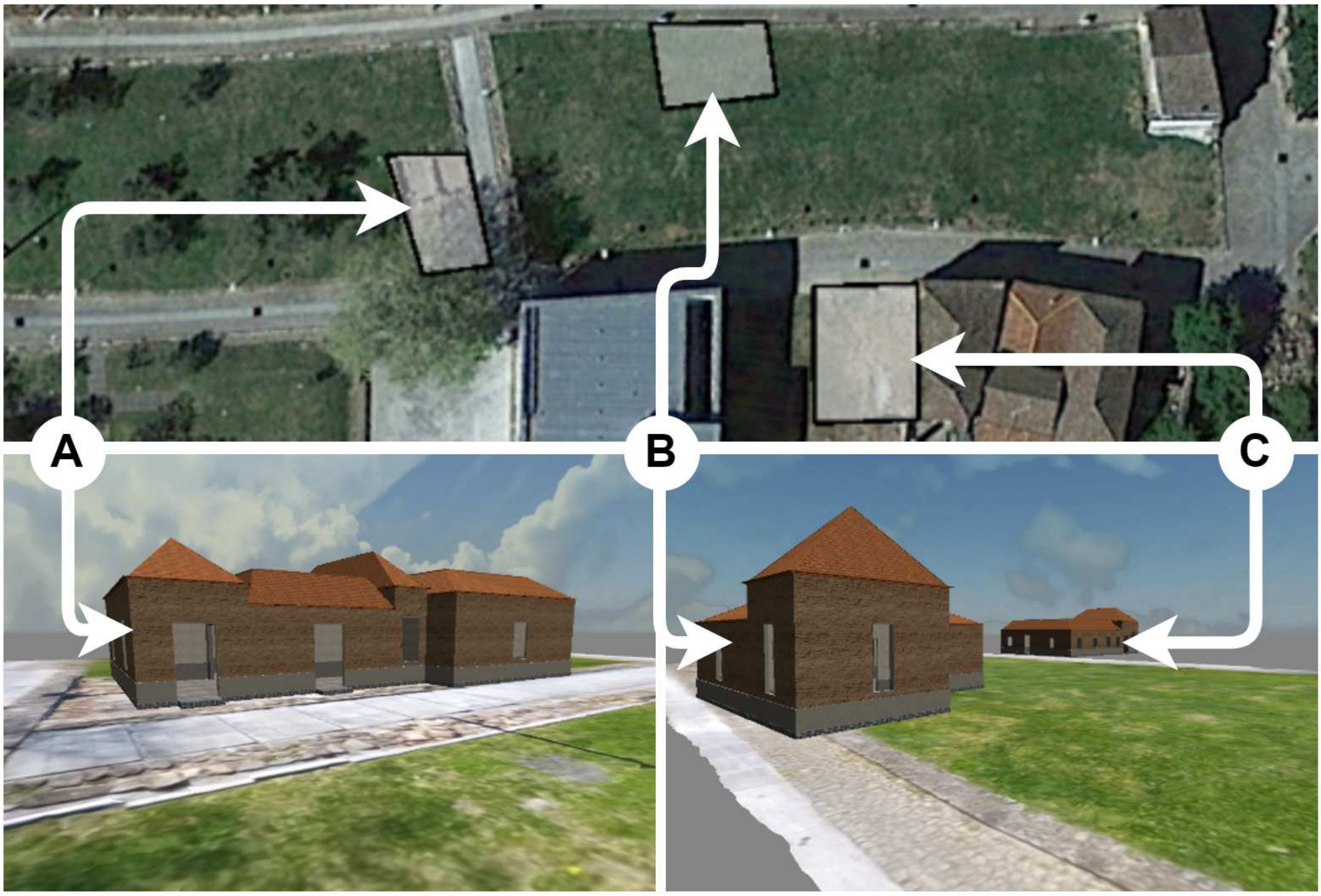

Fig. 6. Preliminary results of the tests carried out considering Vila Velha (Vila Real, Portugal) site. The top part of the image presents GIS-based planning of the ruins. Bottom-left part depicts a hypothetical virtual building placed upon the city's gate ruin (A). At the bottom-right part, there is a couple of fictitious ruins deliberately outlined for testing purposes, each one superimposed by a virtual building hypothesis (B and C).

a process for setting up the enhanced VR environment puts everything together and places the procedurally modelled virtual buildings upon the outlined ruins with the proper rotation and scale. A preliminary test was made using Vila Velha (Vila Real, Portugal) as a cultural heritage site of interest, pointing out the effectiveness of the methodology and related system.

Future efforts will be developed to turn ruins identification into an automatic process, by studying the possibility of integrating image processing and machine learning approaches. Additionally, tests need to be carried out with participants to evaluate the system's usability.

Acknowledgment

This work was financed by the European Regional Development Fund (ERDF) through the Operational Programme for Competitiveness and Internationalisation - COMPETE 2020 under the PORTUGAL 2020 Partnership Agreement, and through the Portuguese National Innovation Agency (ANI) as a part of project "PARRA - Plataforma integrAda de monitoRização e avaliação da doença da flavescência douRada na vinhA" (Nº 3447) and ERDF and North 2020 - North Regional Operational Program, as part of project "INNOVINE&WINE - Vineyard and Wine Innovation Platform" (NORTE-01-0145-FEDER-000038).

References

[1] T. Adão, L. Magalhães, and E. Peres, *Ontology-based procedural modelling of traversable buildings composed by arbitrary shapes*. Springer International Publishing, 2016, vol. 1.

[2] P. Milgram, H. Takemura, A. Utsumi, and F. Kishino, "Augmented reality: A class of displays on the reality-virtuality continuum," in *Photonics for industrial applications*. International Society for Optics and Photonics, 1995, pp. 282–292.

[3] M. Carrozzino and M. Bergamasco, "Beyond virtual museums: Experiencing immersive virtual reality in real museums," *Journal of Cultural Heritage*, vol. 11, no. 4, pp. 452–458, 2010.

[4] F. Bruno, S. Bruno, G. De Sensi, M.-L. Luchi, S. Mancuso, and M. Muzzupappa, "From 3d reconstruction to virtual reality: A complete methodology for digital archaeological exhibition," *Journal of Cultural Heritage*, vol. 11, no. 1, pp. 42–49, 2010.

[5] M. D. Robles-Ortega, F. R. Feito, J. J. Jiménez, and R. J. Segura, "Web technologies applied to virtual heritage: An example of an iberian art museum," *Journal of Cultural Heritage*, vol. 13, no. 3, pp. 326–331, 2012.

[6] R. Gaugne, J.-B. Barreau, G. Le Cloirec, and V. Gouranton, "Experiencing the past in virtual reality: A virtual reality event for the french national days of archaeology," in *Cognitive Infocommunications (CogInfoCom), 2013 IEEE 4th International Conference on*. IEEE, 2013, pp. 75–80.

[7] C. Kiourt, A. Koutsoudis, and G. Pavlidis, “Dynamus: a fully dynamic 3d virtual museum framework,” *Journal of Cultural Heritage*, vol. 22, pp. 984–991, 2016.

[8] B. J. Fernández-Palacios, D. Morabito, and F. Remondino, “Access to complex reality-based 3d models using virtual reality solutions,” *Journal of Cultural Heritage*, vol. 23, pp. 40–48, 2017.

[9] H. Rua and P. Alvito, “Living the past: 3d models, virtual reality and game engines as tools for supporting archaeology and the reconstruction of cultural heritage–the case-study of the roman villa of casal de freiria,” *Journal of Archaeological Science*, vol. 38, no. 12, pp. 3296–3308, 2011.

[10] A. Bustillo, M. Alaguero, I. Miguel, J. M. Saiz, and L. S. Iglesias, “A flexible platform for the creation of 3d semi-immersive environments to teach cultural heritage,” *Digital Applications in Archaeology and Cultural Heritage*, vol. 2, no. 4, pp. 248–259, 2015.

[11] M. Mortara, C. E. Catalano, F. Bellotti, G. Fiucci, M. Houry-Panchetti, and P. Petridis, “Learning cultural heritage by serious games,” *Journal of Cultural Heritage*, vol. 15, no. 3, pp. 318–325, 2014.

[12] V. Vlahakis, M. Ioannidis, J. Karigiannis, M. Tsotros, M. Gounaris, D. Stricker, T. Gleue, P. Daehne, and L. Almeida, “Archeoguide: an augmented reality guide for archaeological sites,” *IEEE Computer Graphics and Applications*, vol. 22, no. 5, pp. 52–60, 2002.

[13] P. Dahne and J. N. Karigiannis, “Archeoguide: System architecture of a mobile outdoor augmented reality system,” in *Mixed and Augmented Reality, 2002. ISMAR 2002. Proceedings. International Symposium on*. IEEE, 2002, pp. 263–264.

[14] J.-G. Han, K.-W. Park, K.-J. Ban, and E.-K. Kim, “Cultural heritage sites visualization system based on outdoor augmented reality,” *AASRI Procedia*, vol. 4, pp. 64–71, 2013.

[15] A. Bellini, C. Luddi, S. Naldini, C. Ghetti, E. Bellini, and G. Bergamin, “" once upon a time": A proof of concept augmented reality collaborative mobile application to discover city heritage,” in *Signal-Image Technology & Internet-Based Systems (SITIS), 2013 International Conference on*. IEEE, 2013, pp. 358–363.

[16] K. Ikeuchi, “e-heritage, cyber archaeology, and cloud museum,” in *Culture and Computing (Culture Computing), 2013 International Conference on*. IEEE, 2013, pp. 1–7.

[17] Y. Blanco-Fernández, M. López-Nores, J. J. Pazos-Arias, A. Gil-Solla, M. Ramos-Cabrer, and J. García-Duque, “Reenact: A step forward in immersive learning about human history by augmented reality, role playing and social networking,” *Expert Systems with Applications*, vol. 41, no. 10, pp. 4811–4828, 2014.

[18] D. Narciso, L. Pádua, T. Adão, E. Peres, and L. Magalhães, “Mixar mobile prototype: Visualizing virtually reconstructed ancient structures in situ,” *Procedia Computer Science*, vol. 64, pp. 852–861, 2015.

[19] K. Themistocleousa, A. Agapioua, and D. Hadjimitsisa, “3d documentation and bim modeling of cultural heritage structures using uavs: The case of the foinikaria church.” *International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences*, vol. 42, 2016.

[20] M. L. Brutto, A. Garraffa, and P. Meli, “Uav platforms for cultural heritage survey: first results,” *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. 2, no. 5, p. 227, 2014.

[21] C. Stal, B. Lonneville, T. Nuttens, P. De Maeyer, and A. De Wulf, “Highly detailed 3d modelling of mayan cultural heritage using an uav,” in *25th FIG Congress: Engaging the challenges, enhancing the relevance*. International Federation of Surveyors (FIG), 2014.

[22] A. Arato, F. Garofalo, G. Sammartano, and A. Spanò, “Gathering gpr inspections and uav survey in cultural heritage documentation context,” 2016.

[23] H. Eisenbeiss and L. Zhang, “Comparison of dsms generated from mini uav imagery and terrestrial laser scanner in a cultural heritage application,” *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. 36, no. 5, pp. 90–96, 2006.

[24] C. Achille, A. Adami, S. Chiarini, S. Cremonesi, F. Fassi, L. Fregonese, and L. Taffurelli, “Uav-based photogrammetry and integrated technologies for architectural applications - methodological strategies for the after-quake survey of vertical structures in mantua (italy),” *Sensors*, vol. 15, no. 7, pp. 15 520–15 539, 2015.

[25] D. Meyer, M. Hess, E. Lo, C. E. Wittich, T. C. Hutchinson, and F. Kuester, “Uav-based post disaster assessment of cultural heritage sites following the 2014 south napa earthquake,” in *Digital Heritage, 2015*, vol. 2. IEEE, 2015, pp. 421–424.

[26] R. Brumana, D. Oreni, M. Alba, L. Barazzetti, B. Cuca, and M. Scaioni, “Panoramic uav views for landscape heritage analysis integrated with historical maps atlases,” *Geoinformatics FCE CTU*, vol. 9, pp. 39–50, 2012.

[27] P. Bourke, “Automatic 3d reconstruction: An exploration of the state of the art,” *GSTF Journal on Computing (JoC)*, vol. 2, no. 3, 2012.

[28] G. Sansoni, M. Trebeschi, and F. Docchio, “State-of-the-art and applications of 3d imaging sensors in industry, cultural heritage, medicine, and criminal investigation,” *Sensors*, vol. 9, no. 1, pp. 568–601, 2009.

[29] M. Dikaiakou, A. Efthymiou, and Y. Chrysanthou, “Modelling the walled city of nicosia,” in *Proceedings of the 4th International Conference on Virtual Reality, Archaeology and Intelligent Cultural Heritage*, ser. VAST'03. Aire-la-Ville, Switzerland, Switzerland: Eurographics Association, 2003, pp. 61–70. [Online]. Available: http://dx.doi.org/10.2312/VAST/VAST03/061-070

[30] P. Müller, T. Vereenooghe, P. Wonka, I. Paap, and L. J. Van Gool, “Procedural 3d reconstruction of puuc buildings in xkipché.” in *VAST*, 2006, pp. 139–146.

[31] B. Tepavčević and V. Stojaković, “Procedural modeling in architecture based on statistical and fuzzy inference,” *Automation in Construction*, vol. 35, no. 0, pp. 329 – 337, 2013. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0926580513000824

[32] K. Dylla, B. Frischer, P. Müller, A. Ulmer, and S. Haegler, “Rome reborn 2.0: A case study of virtual city reconstruction using procedural modeling techniques,” in *37th Proceedings of the CAA Conference*. EG, 2010, pp. 62–66.

[33] P. Müller, P. Wonka, S. Haegler, A. Ulmer, and L. Van Gool, “Procedural modeling of buildings,” in *Acm Transactions On Graphics (Tog)*, vol. 25, no. 3. ACM, 2006, pp. 614–623.

[34] Y. Liu, C. Xu, Q. Zhang, and Y. Pan, “The smart architect: Scalable ontology-based modeling of ancient chinese architectures,” *Intelligent Systems, IEEE*, vol. 23, no. 1, pp. 49–56, 2008.

[35] J. Edelsbrunner, S. Havemann, A. Sourin, and D. W. Fellner, “Procedural modeling of round building geometry,” in *Cyberworlds (CW), 2016 International Conference on*. IEEE, 2016, pp. 81–88.

[36] N. Rodrigues, M. Dionísio, A. Gonçalves, L. M. G. Magalhães, and M. J. P, “Rule-based generation of houses,” *Computer Graphics & Geometry*, vol. 10, no. 2, pp. 49–65, 2008. [Online]. Available: http://cgg-journal.com/2008-2/05/index.html

[37] N. Rodrigues, M. Dionísio, A. Gonçalves, L. G. Magalhães, J. P. Moura, and A. Chalmers, “Incorporating legal rules on procedural house generation,” in *Proceedings of the 24th Spring Conference on Computer Graphics*, ser. SCCG '08. New York, NY, USA: ACM, 2008, pp. 59–66. [Online]. Available: http://doi.acm.org/10.1145/1921264.1921279

[38] N. Rodrigues, L. G. Magalhães, J. P. Moura, and A. Chalmers, “Automatic reconstruction of virtual heritage sites,” in *Proceedings of the 9th International conference on Virtual Reality, Archaeology and Cultural Heritage*. Eurographics Association, 2008, pp. 39–46.

[39] N. Rodrigues, L. Magalhães, J. Moura, A. Chalmers, F. Santos, and L. Morgado, “Archhousegenerator - a framework for house generation,” *Journal For Virtual Worlds Research*, vol. 2, no. 5, 2010. [Online]. Available: https://journals.tdl.org/jvwr/index.php/jvwr/article/view/846

[40] N. Rodrigues, “Rule-based generation of virtual traversable architectural-period houses,” Ph.D. dissertation, University of Trás-os-Montes e Alto Douro, 2010.

[41] N. Rodrigues, L. Magalhães, J. Moura, and A. Chalmers, “Reconstruction and generation of virtual heritage sites,” *Digital Applications in Archaeology and Cultural Heritage*, vol. 1, no. 3, pp. 92–102, 2014.

[42] M. Maciel, *Vitrúvio - Tratado De Arquitetura*. Ist Press, 2006.

[43] T. Adão, R. Batista, E. Peres, L. Magalhães, and A. Coelho, “Reconstructing traversable buildings for archaeology with eras,” in *Proc. Virtual and Networked Organizations: Emergent Technologies and Tools - ViNOrg '13*, 2013.

[44] T. Adão, L. Magalhães, E. Peres, and F. Pereira, “Procedural generation of traversable buildings outlined by arbitrary convex shapes,” *Procedia Technology*, vol. 16, no. 0, pp. 310 – 321, 2014, cENTERIS 2014 - Conference on ENTERprise Information Systems. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S2212017314003247

[45] G. Gröger, T. H. Kolbe, C. Nagel, and K.-H. Häfele, “OGC City Geography Markup Language(CityGML) Encoding Standard,” Open Geospatial Consortium, Tech. Rep., 2012.

[46] GeoDataSource, “Calculate Distance by Latitude and Longitude using C#.” [Online]. Available: http://www.geodatasource.com/developers/c-sharp